TECHNISCHE
UNIVERSITÄT
DRESDEN

Faculty of Computer Science Institute of Systems Architecture, Operating Systems Group

COMPLEX LAB SYSTEMS PROGRAMMING

DAY 1: TOOLS AND BUILD SYSTEMS

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Earning Credits

- you can get credits within the modules INF-MA-PR, INF-E-4, and DSE
- 4 week-hour complex lab
- solve practical assignments after the workshop

Duty Roster

- start at 9.30 AM each morning
- end at latest 3.30 PM
- lunch break
- additional breaks on demand
- ask questions early and often
- feedback is very welcome

Topics

- Day 1: Tools and Build System
- Day 2: C++ Basics & Details
- Day 3: Rust for Systems
- Day 4: Inline Assembler
- Day 5: Debugging Techniques
- Day 6: Multithreading
- Day 7: Underneath POSIX

Today’s Agenda

- programming without an IDE
- dissecting a compiler invocation
- various tools to inspect the results
- static and dynamic linking
- automating with make

Exercise 1: First Steps

- create a directory where you will file all course material
- create a subdirectory in it named `day1`
- in there, create a subdirectory named `exercise1`
- in this subdirectory, create a file `hello.c` using a text editor and enter the following code:

```
int main(void)
{
  printf(”Hello World\n”);
}
```

- indicate when you are done

Exercise 1: First Steps

- change into the directory `exercise1` and run `gcc hello.c`
- run the created file
- What does the warning mean?
- edit `hello.c` to fix the warning
- recompile and run again
- change compiler command to create an executable named `hello`

Exercise 2: Arguments

- change hello to take command line arguments
  - hint: change main to
    ```
    int main(int argc, char *argv[])
    { … }
    ```
- print the first argument after the „Hello World“ default text
- make sure to check the number of arguments (`argc`) before accessing the `argv` array

Exercise 2: Format Strings

- the `%` is special in printf strings
- placeholder where succeeding parameters are inserted
  - `%s` C-string
  - `%c` single character
  - `%d` signed decimal
  - `%u` unsigned decimal
  - `%p` pointer
- don't do this: `printf(argv[1]);`
- instead, do this: `printf("%s\n", argv[1]);`

Exercise 3: Moving to C++

- create a new directory `exercise3` next to `exercise1`
- copy `hello.c` to `exercise3/hello.cc` and open `hello.cc` in your editor
- convert the code to C++
    - use `std::cout` instead of `printf`
    - include `<iostream>` instead of `<stdio.h>`
- compile the file:
  `gcc -Wall -o hello hello.cc`

Exercise 4: Dissecting g++

- pre-process
  `g++ -E -o hello.i hello.cc`
- compile
  `g++ -S -g -o hello.s hello.i`
- assemble
  `g++ -c -g -o hello.o hello.s`
- link
  `g++ -o hello hello.o`

Exercise 4: Dissecting g++

- compare object file of C++ source to object file of C source
- check size of executable `hello`
- check output of `nm hello`
- call `strip hello` and check size of `hello` and `nm`-output again

Making Friends with make

- `make` conditionally runs shell commands
- often used for build systems, can do a lot more
- automatically determines, which parts of a program need to be recompiled
- speeds up development and prevents forgotten recompiles
- a `Makefile` is a list of rules

```
target: prerequisites
        commands
```

- by default, `make` executes the first rule of `Makefile`, traditionally using target name `all`

Exercise 5: Using make

- delete the `hello` binary
- write a `Makefile` to create `hello` from `hello.cc`
- call `make` twice and make sure it does not recompile
    - hint: `make` only executes a target's commands, if the target does not exist or any of the prerequisites is newer

Exercise 5: Using make

- modify the `Makefile` to treat warnings as errors
- Why does `make` not recompile?
- modify `Makefile` to fix

Exercise 5: Using make

- create a function `name` without parameters or return value that prints your name
- call that function `name` from the `main` function in the file `hello.cc`
- we don't use command line arguments any more
- `make` and run `hello`

Exercise 5: Using make

- move the code of the function `name` into an own source file `name.cc`
    - only move the `name` function, `main` stays in `hello.cc`
    - in `hello.cc`, add the line `void name();` instead
- modify `Makefile` to also compile and link `name.cc`
    - create one binary `hello`
- fix the errors and warnings and rerun `make`

Exercise 5: A Possible Solution

```
SRC = hello.cc name.cc
OBJ = $(SRC:.cc=.o)

hello: $(OBJ)
	g++ -o $@ $+

%.o: %.cc Makefile
	g++ -Wall -Werror -c -o $@ $<
```

Header Files

- function **declarations** make a function and its signature known within a scope

```
void name();
```

- function **definitions** define what is done whenever the function is invoked

```
void name()
{
  std::cout << “name” << std::endl;
}
```

Header Files

- declarations provide the interface, definitions the functionality
- header files are used to publish declarations
- the header file is included
  - where the function is used, so the compiler knows about it and can check the signature
  - where the function is defined, to detect mismatches between declaration and definition

Exercise 6: Header Files

- write and use a header file `name.hh` for the function `name`
- What is the difference between
  `#include <name.hh>`
  and
  `#include "name.hh"`

Exercise 7: Inline Functions

- for very small helper functions, the function call overhead can be avoided by inlining
- make the `name` function an inline function by moving its definition from `name.cc` to `name.hh`
  - hint: prepend the definition with the `inline` keyword
- What happens, if `hello.cc` includes `name.hh` more than once?

- note: this is a sidetrack, we will come back to the un-inlined version after this exercise

Exercise 8: More make Magic

- add a clean rule to remove generated files
- use dependencies to enable recompiles on header changes
    - find the `g++` option to generate a dependency file from a source file
    - extend `Makefile` to generate dependency files
    - use them in the `Makefile`

Exercise 8: A Possible Solution

```
SRC = hello.cc name.cc
OBJ = $(SRC:.cc=.o)
DEP = $(SRC:.cc=.d)

hello: $(OBJ)
	g++ -o $@ $+

%.o: %.cc Makefile
	g++ -MMD -Wall -Werror -c -o $@ $<

clean:
	rm -f $(OBJ) $(DEP) hello

-include $(DEP)
```

Libraries

- common platform functions are used by virtually every program
- code is packaged into libraries
- static and dynamic libraries
- static libraries
  - are just archives of object files
  - are linked with your own object files into a binary at compile time
  - not relevant at runtime
  - are created with `ar`
  - a symbol index is added with `ranlib`

Exercise 9: Static Library

- create a new directory `exercise9`
- copy your final `hello.cc`, `name.cc`, `name.hh` and `Makefile` there
- turn `name.cc` into a static library `libname.a`
  - bonus points for implementing recursive make
  - create a subdirectory `lib` for `name.*`
  - create a `Makefile` in that subdirectory to create the static library
  - modify the existing `Makefile` to also build in the `lib` subdirectory

Exercise 9: Solution Snippet 2

```
SRC = hello.cc
LIB = libname.a

hello: hello.o $(LIB)
	g++ -o $@ $+

$(LIB): name.o
	ar -cr $@ $+
	ranlib $@

%.o: %.cc Makefile
	g++ -Wall -Werror -c -o $@ $<
```

Dynamic Libraries

- linked in two stages
  - at compile time, the linker only verifies that all symbols are available
  - at runtime, the dynamic loader
    - checks, what libraries the executable needs
    - loads them into memory
    - attaches them to the executable
- advantages:
  saves disk space and memory due to sharing
- disadvantage:
  longer application startup time

Exercise 10: Dynamic Library

- turn `libname.a` into a dynamic library `libname.so`
- hint: `g++ -shared` might be interesting to you
  - use `-dynamiclib` on macOS
- run `ldd` on your dynamically linked `hello` binary

Recap

- learned what a compiler does
- how to use header files
- static and dynamic libraries
- automating build commands with `make`
- subversion source code management
- tools: `file`, `nm`, `objdump`, `strip`, `ldd`